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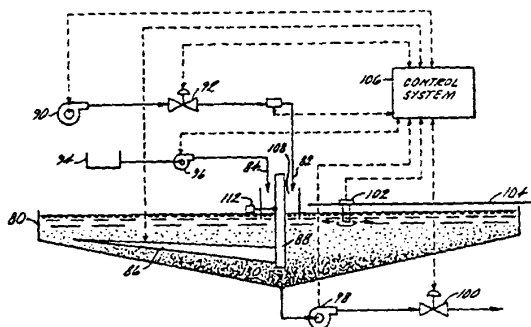
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(71) Applicant: BAKER HUGHES INCORPORATED [US/US]; Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).		Published With international search report.	
(72) Inventors: NELSON, Michael, G.; 7891 South Honeywood Hill Lane, Salt Lake City, UT 84121 (US). HALES, Lynn, B.; 626 Little Tree Circle, Salt Lake City, UT 84108 (US). SCHOENBRUNN, Fred; 8472 Kings Cove Drive, Salt Lake City, UT 84121 (US).			
(74) Agents: ROWOLD, Carl, A. et al.; Baker Hughes Incorporated, Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).			

(54) Title: METHOD AND APPARATUS FOR CONTROLLING THICKENERS, CLARIFIERS AND SETTLING TANKS



(57) Abstract

Computerized, "intelligent" systems and methods for monitoring, diagnosing, operating and controlling various parameters and processes of thickeners, clarifiers, and settling tanks are presented. The computer control system actuates at least one of a plurality of control devices based on input from one or more monitoring sensors so as to provide real-time, continuous, operational control. The response of the control system is based on the system's own process model, which in turn is based on sensor input and one or more advanced analysis techniques including, but not limited to, neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, and combination thereof. Process and operating parameters of particular interest include rate and amount of chemical (flocculant) addition, power consumption, control of underflow/overflow rates and composition, and control of the drive mechanism. In a particularly preferred embodiment, the apparatus comprises a thickener or the like with at least one sensor for providing input consisting of a continuous profile of the settling zone and the bed, which is analysed by a process model generated by a combination of statistical methods and neural networks. As a result of the analysis, at least one output may be generated to activate a control device that effects changes in operating variables as suggested by the process model and leads to optimization of the operation of the thickener. Preferably, the sensor(s) is a non-invasive sensor such as an ultrasonic (sonar) or millimeter-wave radar sensor.

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METHOD AND APPARATUS FOR CONTROLLING THICKENERS,
CLARIFIERS AND SETTLING TANKS

Background of the Invention:

5 1. Field of the Invention

This invention relates generally to thickeners, clarifiers, settling tanks and like equipment which are generally used for the separation of particles from a liquid slurry or pulp. More particularly, this invention relates to methods and apparatus for automatically monitoring, operating, and controlling thickeners, clarifiers, settling
10 tanks, and the like using "intelligent" computer control systems and remote sensing devices.

2. Brief Description of the Prior Art

Slurries or suspensions comprising liquids carrying suspended particles are typically subjected to a process called clarification to separate suspended particles from
15 supernatant liquid. Typically, clarification is accomplished by continuously feeding an influent slurry or suspension feed stream into a settling tank, clarifier or thickener, where suspended particles are allowed to gravity settle and form a sludge or thickened mud on the bottom of the tank. The thickened material (or thickener underflow) is
20 removed and further processed or disposed of, while the clarified liquid supernatant (or thickener overflow) is either discharged, reused, or subjected to further clarification.

A thickener usually is a vertically positioned, cylindrical vessel of a size determined by the amount of slurry to be treated in a given unit of time. The central portion of the bottom of the thickener usually is conical and slopes downwardly
25 towards the underflow discharge port. Slurry which comprises finely divided solid particles and solution is fed into the upper part of the thickener. Solid particles settle towards the bottom and solution rises to the top. A conventional rake mechanism is provided and is rotated at a speed determined by the solids settling rate to produce a solids-liquid ratio desired in the underflow, from which optimum results are obtained in
30 the following solids-liquid separation step.

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The sedimentation process is sometimes expedited by adding a flocculating reagent to the influent before it enters the settling tank. The flocculating reagent typically has a polymeric molecular structure which agglomerates with suspended particles in the influent to form aggregate clusters called flocs. Flocs have a greater
5 density or effective diameter than the discrete suspended particles, and settle to the floor of the tank quickly.

There are generally four distinct zones of settling slurry within the thickener. At the top there is a zone of clear water. Beneath this is a zone consisting of aggregates or flocs of solid particles of uniform consistency. This zone is commonly
10 referred to as the zone of flocculated slurry. Beneath this zone is a transition zone and at the bottom a zone of pulp which is undergoing compression and in which the flocs have settled to a point where they rest directly one upon another. The specific gravity of the underflow slurry closely approximates the specific gravity of the slurry in the compression zone. The pulp in the transition zone decreases in percentage solids from
15 the bottom, where flocs enter, to the top, where the consistency of the flocculated pulp is the same as that of the original slurry.

Automatic control and optimized operation of thickeners has been a continuing concern and objective of thickener operators and manufacturers. Typically, such automatic control systems utilize a sensor which communicates process information to
20 a controller whereby the process is in some way altered. A number of sensors have been proposed in the prior art. For example, several prior art references disclose the use of photodetectors, light sensors, and other optical components in conjunction with thickener control systems. In Japanese Patent No. 259902, a plurality of television cameras is arranged in a settling cell. These cameras detect the grain size distribution
25 and compare the detected image to standard distribution conditions to control flocculant formation. The use of light sensors is disclosed in U.S. Patent Nos. 4,279,759 and 4,976,871. More particularly, these two references disclose the use of photosensors comprising a light source and a photo cell to measure the concentration of suspended solids, based on such measurements, the rate of flocculant introduction
30 to the cell is controlled. Similarly, U.S. Patent No. 5,240,594 discloses a system for

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monitoring and/or controlling a liquid/solid separator using photodetectors which view the surface of the composition being separated and correlate the corresponding signals from the photodetectors to a dryness value.

U.S. Patent Nos 3,375,928, 3,551,330, and 4,348,278 all disclose the use of
5 pressure sensors for monitoring the interface levels in a settling tank. In addition to monitoring the interface, some of these patents also monitor density, as do U.S. Patent No. 4,273,658 ('658) and Australian Patent No. 75958. The '658 patent utilizes a radioactive based sensor for sensing density. The sensor is lowered on a cable to provide a profile along the depth of the thickener. Similarly, the Australian patent
10 discloses a device which is lowered on a cable for measuring density. The device includes two rigidly spaced, ultrasonic transducers, which transmit signal through a fixed path length, thereby determining density.

U.S. Patent No. 4,040,954 utilizes a turbidity sensor probe to continuously monitor turbidity and compare such monitored turbidity to a desired value or set point.
15 The probe is raised or lowered to maintain the known set point. The supply of flocculant is controlled in response to change in turbidity and position of the probe. U.S. Patent No. 4,226,714 discloses a thickener which maintains steady state by controlling mass flow rates of influent to and underflow from the separator. This control system uses influent specific gravity and flow rate signals for such control.

20 U.S. Patent No. 4,867,886 discloses a non-contact sensor, based on sonic or laser proximity technology for reporting the cake surface. In response to the sensor signal, flocculant flow rate is adjusted.

U.S. Patent No. 4,876,888 utilizes a simple level sensor comprising a float strung on a continuous line to monitor level and control the amount of flocculant
25 introduction. In general, level sensing in the prior art is accomplished by a wide variety of devices including the capacitive proximity sensors disclosed in U.S. Patent Nos. 5,305,779 and 4,888,989.

U.S. Patent Nos. 5,013,442 and 5,094,752 disclose the use of an alkalinity profile of the influent which is measured at a plurality of different points in the process.

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When the sensed alkalinity at any given point is more than a predetermined amount above a base line alkalinity, a change is made.

U.S. Patent No. 5,183,562 controls the addition of flocculant using measurements made by a heat transfer detector and an electric conduction meter. U.S. Patent No. 4,783,314 discloses the use of fluorescent tracers in separation equipment.

In general, all of the aforementioned thickener control techniques involve simple feedback or feed forward control loops and utilize a narrow range of sensors and control devices which limit the overall ability of the operator to provide an accurate system control. Furthermore, it is not believed that any of the aforementioned prior art provides a comprehensive, computerized, "intelligent" control system for operating, controlling, and monitoring various thickeners, clarifiers, settling tanks, and like equipment. The ability to provide, precise, real time control and monitoring of such equipment constitutes an on-going, critical industrial need.

Summary of the Invention:

The above-discussed and other problems and deficiencies of the prior art are overcome or alleviated by the several methods and apparatus of the present invention for providing computerized, "intelligent" systems for operating, controlling, monitoring and diagnosing various parameters and processes of thickeners, clarifiers, settling tanks, and like equipment. For purposes of this invention, any reference to "thickener" shall include all equipment of the type where solids are separated from liquids through settling in a tank, including the aforementioned clarifiers and settling tanks.

In accordance with the present invention, a computer control system actuates at least one of a plurality of control devices based in part on input from one or more monitoring sensors so as to provide real time continuous operational control.

It will be appreciated that it is difficult to sense and communicate certain parameters in real time within thickeners. Thus, in accordance with an important feature of the present invention, a variety of technologies including ultrasonic, absorption and reflection, laser heated cavity spectroscopy, X-ray fluorescence

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spectroscopy, neutron activation spectroscopy, pressure measurement, microwave or millimeter wave radar, reflectance or absorption, and other optical and acoustic methods may be utilized. In addition, several novel communications methods for transmitting and receiving data and power to and from the interior of the thickener are provided. Such communications techniques may include hard-wired electrical systems, optical systems, RF systems, acoustic systems, video systems, and ultrasonic systems.

In a preferred embodiment, the sensor or sensors comprises a non-intrusive (non-invasive) or nearly non-intrusive (nearly non-invasive) system for determining bed profile (preferably both vertically and horizontally). Such a non-intrusive (or invasive) sensor is distinguishable from intrusive sensors known in the prior art such as probes lowered into a bed. Such prior art intrusive sensors typically require struts and other structure within the tank which impede settling and rake movement. A non-intrusive sensor avoids these problems. A nearly non-intrusive sensor is installed slightly below the surface of the liquid in the thickener tank, but is not required to travel to any greater depth. Neither the non-intrusive nor the nearly non-intrusive type sensors require extraction of samples for extended analysis. As used hereinafter, the term "non-intrusive" sensor shall include both the non-intrusive and nearly non-intrusive sensors discussed above.

Preferred, non-intrusive sensors include ultrasonic sensors, sonar sensors and millimeter-wave radar based sensors. Such sensors may oscillate in an arcwise path or may move linearly along a radius of the tank to provide a bed profile of the entire tank or at least that portion of the tank which is of interest. Also, multiple, spaced sensors may be used to obtain a complete bed profile.

The response of the control system is preferably based on a series of expert rules, determined initially in advance and continually updated based upon the control system's own analysis of its performance. The control system preferably generates and continuously updates its own "process model," using the data inputs described above and one or more of several advanced analysis techniques, including but not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, signal processing, pattern recognition, categorical analysis, statistical analysis or a combination thereof.

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Preferably, the control system has the ability to independently select the best analysis technique for the current data set. Thus, the computer controller may actuate one or more control devices to control any number of process and operational control variables based not only on one or more of the sensor inputs but also on the currently selected process model.

The computer controller used in the system of the present invention is preferably a personal computer or workstation, with a display device (CRT screen) and input/output device (keyboard or touch-sensitive screen). The microprocessor controller may be located at the thickener or at a remote location such as a central control room in a plant. Importantly, the controller may control one or a plurality of thickeners at a single or plurality of sites.

The above-described computerized control and monitoring system for thickeners provides a comprehensive scheme for monitoring and controlling a variety of input and output parameters as well as a plurality of operational parameters resulting in greater efficiency, optimization of operation, and increased safety.

The above-discussed and other features and advantages of the present invention will be appreciated and understood by those skilled in the art from the following detailed description and drawings.

Brief Description of the Drawings:

Referring now to the drawings wherein like elements are numbered alike in the several FIGURES:

FIGURE 1 is a schematic, sectional view of a conventional thickener with which the monitoring and control system of the present invention is used;

FIGURE 2 is a schematic of the monitoring and control system for a thickener in accordance with the present invention;

FIGURE 3 is a schematic of a preferred monitoring and control system employing a non-intrusive sensor system;

FIGURES 4 is a schematic of a monitoring and/or control system employing a non-intrusive sensor system for a tank containing a multiphase material.

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FIGURE 5 is a schematic of a top view of a typical sensor mounting and scanning axis employing a non-intrusive sensor;

FIGURE 6 is a schematic of a side view of a typical sensor mounting and scanning axis of a non-intrusive sensor;

5 FIGURE 7 is a schematic of a video display color coded for return signal strength of a sonar sensor signal in scanning mode; and

FIGURE 8 is a schematic of a video display of return signal strength of a sonar sensor signal in fixed mode.

10 Description of the Preferred Embodiment:

 This invention relates to methods and apparatus for automatically controlling, operating, and monitoring thickeners using "intelligent" computer controlled systems and remote sensing devices. By "intelligent" is meant the use of computer control methods including but not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof to analyze input in terms of one or more self-generated, continuously updated, internal models, and to make changes in operating variables as suggested by the models. It is to be understood that the term thickener is used in its most general sense, being inclusive of traditional separation cells, clarifiers, and thickeners wherein solids and liquids are separated by a settling process. It is further to be understood that a thickener in the context of the present invention may refer to a single tank or column or to a bank of tanks or columns.

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 Referring to FIGURE 1, a simplified example of a thickener contemplated by the present invention is shown. In FIGURE 1, a conventional thickener or settling tank is shown at 10. Conventionally, it is a cylindrical vessel of a height and diameter determined by the nature of the slurry and the desired slurry underflow output per unit of time. It may or may not be covered, or shown in FIGURE 2.

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 The thickener is provided with an inlet conduit 12 which is connected to a source of slurry to be treated. The conduit 12 extends into the top of the thickener.

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An overflow launder 14 surrounds the top of the thickener in which the overflow is collected and passed to further treatment.

The thickener bottom has a conical central portion 16 which slopes downward from a generally sloping lower wall or floor 18 towards a discharge outlet 20 at the center thereof. A rake 22 is positioned near the bottom and is rotated to move solids radially inward toward outlet 20.

The feed of slurry to the thickener, the overflow of clear liquid from launder 14 and the discharge of thickener underflow from outlet 20 are continuous. The rates of feed and discharge are usually adjusted to achieve a high solids concentration underflow slurry while maintaining the solids concentration of the overflow below a predetermined limit.

The profiles of the zones of settling slurry within the thickener will depend upon the nature of the slurry and the rates of feed and discharge, as well as the addition of chemical flocculants. The profile in dashed lines in the drawing are illustrative of what may be typical boundaries between zones of a slurry. The rate of feed of the slurry to the thickener and the rate of discharge therefrom are adjusted to maintain the specific gravity of the slurry at one of the levels indicated by the profile lines in the drawing. The numeral 24 designates the upper zone of clear liquid and numeral 26 designates the zone of flocculated slurry of uniform consistency. Numerals 28 and 30 identify a transition zone and a compression zone, respectively. Beneath compression zone 30 at the periphery of the thickener is a dead-bed 32.

A conduit 34 is connected to the outlet port 20 which conduit extends to a variable speed pump 36. This pump 36 is of a conventional type, such as a centrifugal pump, for pumping mixtures of solids and liquids. A conduit 38 extends from pump 36 to an optional solids-liquid separation apparatus, not shown.

In accordance with the present invention, thickeners of the type discussed above are provided with one or more sensors for the sensing of one or more parameters related to the processes and operation of the thickeners. In addition, a computerized control system which may be located at the thickener, near the thickener, or at a remote location from the thickener is provided for interaction with the sensor or

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sensors in the thickener. This computer control system includes a control computer and one or more control devices which are actuated in response to a command signal from the control computer. Importantly, the response of the control system will preferably be based both on sensor input and on a series of expert rules, determined initially in advance and continually updated based upon the control system's own analysis of its performance. The controller will generate and continuously update its own "process model," using the data inputs described and one or all of several advanced analysis techniques, including neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, or a combination of these. The control system will have the ability to independently select the best analysis technique for the current data set. The computer control system will actuate one or a plurality of control devices based on input from one or more monitoring sensors so as to provide real time, continuous, operational control. In addition, the control system may include a monitoring system for data logging, preventative maintenance, or failure and wear prediction. The control system may additionally include diagnostics relating to the condition of the equipment.

Referring now to FIGURE 2, a schematic is shown depicting examples of the monitoring sensors, control devices, and components and features of the control system of this invention. FIGURE 2 more particularly shows a thickener 40 having associated therewith one or more process sensors 42 and/or one or more equipment sensors 44, and preferably includes sensors 46 for providing a real time, continuous bed profile. In addition, the thickener is associated with one or more operational control devices 48. The sensors 42, 44, and 46 communicate through an appropriate communications system, i.e., an analog and/or digital data acquisition interface 50 with the central control computer 52. The control devices 48 communicate through an appropriate communications system, i.e., an analog and/or digital control output interface 54 with the central controller 52. As previously mentioned, the control computer 52 may be located on the thickener, near the thickener, or at a remote location such as a control room. Computer 52 has associated therewith a display 56 for displaying data and other parameters, a keyboard 58 or other means for inputting

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control signals, data, and the like, a memory or recorder 60, and a modem 62 for inputting and outputting data to the computer 52 from remote locations.

Still referring to FIGURE 2, the microprocessor controller 52 receives a variety of inputs which have been categorized generally in terms of (1) information stored in memory when the thickener is manufactured; (2) information programmed at the site
5 where the thickener is to be used; (3) process parameters sensed by the process sensors 42; and (4) equipment (operational) parameters sensed by the equipment sensors 44.

The outputs from the control computer may be generally categorized as (1) data stored in memory 60 associated with the computer 52; (2) operational control of the
10 thickener; and (3) real time information provided to the operator at the monitor 56 associated with the computer 52. The various inputs and outputs are summarized in the following Table.

TABLE

<u>INPUTS</u>		<u>OUTPUTS</u>	
1.	INFORMATION ORIGINALLY STORED IN MEMORY	1.	DATA STORED IN MEMORY
5	OPERATIONS MAINTENANCE INFORMATION		OPERATING DATA
	TRAINING INFORMATION		PREVENTATIVE MAINTENANCE INFORMATION
	PROCESS MODELS		FAILURE AND WEAR PREDICTION
	PROCESS CONTROLS, GUIDELINES		
2.	INFORMATION PROGRAMMABLE AT SITE	2.	OPERATIONS CONTROLLED
10	OPERATING RANGES		VOLUME OR MASS FLOW RATES
	OUTPUT PARAMETERS DESIRED		PARTICLE SIZE, CONCENTRATION AND DISTRIBUTION
	SITE SPECIFIC (E.G., ENVIRONMENTAL) DATA		FLOCCULANT ADDITION
	PROCESS MODELS		RAKE SPEED
15	PROCESS CONTROLS, GUIDELINES		CONTROL OF VALVES AND FLOW ORIFICES
			RAKE LIFT
			POWER DRAW
			UNDERFLOW DENSITY
			UNDERFLOW RHEOLOGY
			RAKE CONFIGURATION
3.	PROCESS PARAMETERS SENSED	3.	READ OUT AT MONITOR
20	VOLUME AND MASS FLOWS		EQUIPMENT CONDITION DIAGNOSTICS
	CHEMICAL OR MINERALOGICAL COMPOSITION		SPARE PARTS ORDER DATA
	PARTICLE SIZE AND DISTRIBUTION		OPERATING PARAMETERS
	SOLIDS CONCENTRATION		
	FLOCCULANT ADDITION		
	DENSITY		
25	DIGITIZED IMAGES OF STREAMS		
	CONTINUOUS BED PROFILE		
4.	EQUIPMENT PARAMETERS SENSED		
30	RAKE ROTATIONAL SPEED		
	RAKE TORQUE OR POWER DRAW		
	RAKE LIFT		

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Information Stored in Memory

Examples of information originally stored in memory include information relating to the operation and maintenance of the thickener and operator training information, all of which will be readily available to an operator on display screen 56 associated with microprocessor controller 52.

Information Programmed at Site

Examples of information programmed at the site where the thickener is to be used include the operating ranges, equipment parameters, and desired feed parameters, along with other site-specific data such as relative humidity and other environmental factors. Input into the control computer also includes various process models and process controls, and guidelines. These models and goals may be either stored in memory or programmed at the site as appropriate.

Process and Equipment Parameters

A further important feature of the present invention is the large number of process and equipment sensors 42, 44, and 46 which sense a variety of aspects relating to the thickener, its operations, and its feed, underflow, and overflow streams.

Particularly important are sensors relating to rate of chemical addition and the bed profile. Other process parameters which may be sensed include, but are not limited to the volume or mass flow rates into the feed, underflow and/or, overflow streams; the density of the feed, underflow and/or overflow streams; the chemical or mineralogical composition of the feed, underflow and/or overflow streams; the particle size, concentration, and distribution of solids in the feed, underflow and/or overflow streams; or digitized video images of the surface or other key parts of the process, analyzed to determine the key characteristics of the subject being imaged.

Equipment parameters which may be sensed include but are not limited to rake speed, rake torque, rake power consumption, or rake lift above the floor of the thickener.

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Since the mode of operation of a sensor may vary in terms of the emitted frequency, signal strength, and threshold return (noise cutoff) from one installation to the next, preferably, each sensor is programmed to initialize itself by sweeping a range of frequencies, signal strengths and threshold returns to find an effective value for each of these parameters.

It will be appreciated that it is often difficult to sense and communicate certain parameters in real time within thickeners. Thus, a variety of technologies including laser based system which determine liquid/solid and like interfaces within a liquid body, laser-heated cavity spectroscopy, laser-induced breakdown (LIB) spectroscopy, laser-induced mass spectroscopy, ultrasonic, sonar, pressure measurement, X-ray fluorescence spectroscopy, neutron activation spectroscopy, microwave or millimeter-wave radar reflectance or absorption, and other optical and acoustic methods may be utilized in the present invention. A suitable microwave sensor for sensing moisture and other constituents in the solid and liquid phase influent and effluent streams may be measured using the instrumentation described in U.S. Patent 5,455,516, all of the contents of which are incorporated herein by reference. An example of a suitable apparatus for sensing using LIB spectroscopy is disclosed in U.S. Patent 5,379,103, all of the contents of which are incorporated herein by reference. A preferred embodiment employing a non-intrusive sensor system such as an ultrasonic, sonar, laser or millimeter-wave radar sensor is described in detail hereinafter with reference to FIGURES 3 -8.

Suitable techniques for communicating among the sensors, microprocessor, and other components include hard-wired electrical systems, optical systems, RF systems, acoustic systems, video systems, and ultrasonic systems.

Data Stored in Memory

Referring more particularly to the data stored in memory, it will be appreciated that the computerized monitoring and control system of this invention may utilize the aforementioned sensors to monitor various parameters with respect to time and thereby provide a detailed historical record of the thickener operation 66. This record

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may be used by the microprocessor to model thickener operation, adjust models for thickener operation, or generally learn how the thickener behaves in response to changes in various inputs. At any time, such operating data may be retrieved from a position local to the thickener or remotely. The data may be displayed in real time while the thickener is operating using monitor 56, or as a historical record of some prior operating sequence. This record may also be used to provide a data log, provide trending and preventative maintenance information, predict failure and predict machine wear 68. Pre-formatted reports may present the retrieved data to show information such as operating hours, alarms generated, number of starts, number of trips, electrical power used, maximum and minimum values for measured variables, total feed processed, and the like. Using the operating data, the thickener manufacturer may recommend measures to avoid down time and to optimize run time. Also, maintenance procedures may be suggested based on the operating log of elapsed run time, and unusual operating conditions. The operating data log thus helps to trouble shoot various operating conditions of the thickener. This enhances the thickener manufacturer's ability to solve the customer's operational problems and to keep equipment on line. Optionally, these data 66,68 may then be used to provide alarms or emergency notification 70 when certain critical levels are reached.

Control of Operations

Controller 52 preferably communicates through standard communication cards used on personal computers or workstations. As such, Ethernet, RS-232, and modem capabilities exist for the operator's use. The present invention therefore allows a given plant to collect thickener operating data through a plant-wide Ethernet or other network. Additionally, the present invention may communicate with other process devices not supplied by the manufacturer. In this way the operator uses the control and monitoring system of this invention to gather information on a larger portion of the process.

Using a connected plant network, the operator may monitor the thickener's real time performance and historical log. Suitable software for this activity includes

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operator screens for data display, and message displays for operating assistance, and may also include an on-line operation and maintenance manual. The operator may also control and optimize the performance of the thickener through the plant network. The operating parameters as described below may also become part of an overall

5 Supervisory Control and Data Acquisition (SCADA) system or Distributed Control System (DCS). As is well known, in a SCADA system, or DCS, microprocessor devices convert plant measurement and status inputs into computer data for logging and transmission to higher level processors. Supervisory controllers make strategic decisions for the operation of a process unit or plant and send out set points to

10 dedicated controllers which will make the changes to actuators and ultimately the process as a whole. The SCADA network therefore connects to many controllers and field devices to gather information and make global decisions.

Continuing to refer to FIGURE 2, a further important feature of this invention is that in response to the one or more parameters sensed by the sensors 42, 44, the

15 operation of the thickener and thereby its ultimate efficiency can be adjusted, changed, and preferably optimized using one or more advanced computerized control methods. Such advanced computerized control methods include but are not limited to neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, categorical analysis, or a combination thereof.

20 Thus, in a preferred embodiment, this invention comprises at least one of these control methods and other methods more advanced than conventional, stabilizing control methods, for example, the simple feedback or feed forward control loops of the prior art. The response of the system is based on a series of expert rules, determined initially in advance and continually updated based upon the control system's own

25 analysis of its performance. The control system will generate and continuously update its own "process model" using the sensor inputs described and the above-mentioned analysis techniques. The control system may have the ability to independently select the best analysis technique for the current data set.

While controller 52 may operate using any one or more of a plurality of

30 advanced computerized control methods, it is also contemplated that these methods

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may be combined with one or more of the prior art methods, including feed forward or feedback control loops. Feed forward is where process and machine measurements (or calculated, inferred, modeled variables normally considered ahead of the machine in the process) are used in the controller 52 to effectively control the operation of the thickener. Feed forward schemes inherently acknowledge that the conditions and state of the feed material to the thickener change over time and that by sensing or calculating these changes before they enter the thickener, control schemes can be more effective than otherwise might be possible. Feedback is where measurements and calculated values that indicate process performance and machine state are used by controller 52 and the control scheme contained therein to stabilize the performance and to optimize performance as feed conditions changes and machine performance changes in reference to set points and optimization objectives.

Process and machine models are embedded in controller 52, as are methods to evaluate the models to determine the present and future optimum operating conditions for the machine. Optimum conditions are specified by flexible, objective functions that are entered into the controller 42 by the operators or plant control system that is dealing with plant-wide control and optimization. The models contained therein are adaptive in that their form or mathematical representation, as well as the parameters associated with any given model, can change as required. These models include, but are not limited to first principles and phenomenological models as well as all classes of empirical models that include neural network representations and other state space approaches. Optimization is accomplished by combining the contained knowledge of the process and machine through these models with expert system rules about the same. These rules embody operational facts and heuristic knowledge about the thickener and the process streams being processed. The rule system can embody both crisp and fuzzy representations and combine all feed forward, feedback, and model representations of the machine and process to maintain stable, safe, and also optimal operation including the machine and the process. Determination of the optimum operating states includes evaluating the model representation of the machine and process. This is done by combination of the expert system rules and models in

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conjunction with the objective functions. Genetic algorithms and other optimization methods are used to evaluate the models to determine the best possible operating conditions at any point in time. These methods are combined in such a way that the combined control approach changes and learns over time and adapts to improve performance with regard to the machine and the process performance.

A detailed description of a suitable system employing an internal process model as described herein for use in connection with the present invention is disclosed in U.S. Application Serial No. 60/037,355 filed February 21, 1997, assigned to the assignee hereof, all of the contents of which are incorporated herein by reference.

As discussed above, the adaptive control system of this invention uses one or a combination of internal and/or external machine and/or process variables to characterize or control the performance of the thickener, in terms of the desired process outputs. Preferably, the control system continually updates its knowledge of the process, so that its control performance improves over time.

One of the important calculated values included in this process is the economic performance of the thickener. Economic performance includes base machine operating costs, including power usage and chemical additive usage, and the normalized performance cost dealing with throughput rates and the quality of the products produced both in absolute terms and terms normalized for feed conditions.

Still referring to FIGURE 2, in response to the one or more parameters sensed by the sensors 42 and 44, the advanced control system of the microprocessor may actuate one or more process and/or equipment control devices 48 to control operations. The operational outputs from the central controller 52 may be processed through a control output interface 54. In some cases, the control devices will be actuated if certain sensed parameters are outside the normal or preselected thickener operating range. This operating range may be programmed into the control system either prior to or during operation. Examples of operational parameters which may be adjusted include but are not limited to volume or mass flow rates into the feed, underflow and/or overflow streams; the particle size, concentration, and distribution of solids in the feed, underflow and/or overflow streams; the rate of addition of

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flocculants and other chemical additives; speed of rotation of the rake, rake power consumption; rake configuration, lift of the rake above the floor of the thickener, underflow density, overflow rheology and withdrawal rates of underflow and overflow streams. The foregoing operational controls and examples of actual control devices which will provide such operational control will be described in more detail below.

Readout at Monitor

Referring still to FIGURE 2, other outputs include the real time status of various parameters at the thickener to the operator. Thus, the operator may use the computerized control and monitoring system of the present invention to diagnose the present condition of the equipment, order spare parts (a modem/fax 66 may be included for spare parts ordering), or obtain a read-out as part of a SCADA system or DCS as described above.

A particularly preferred embodiment of the present invention employs an imaging system comprising ultrasonic, sonar or millimeter wave sensors or the like producing a continuous profile bed which is converted to data usable by the process models of the present invention. Continuously measuring and profiling the bed greatly enhances process control since the operator can then optimize the bed gradient in real time by adjusting the flocculant dosage and/or the underflow or overflow withdrawal rates. The data from the ultrasonic, sonar or other imaging system may be interpreted by a video sensor system. Such a system, designed for use in mineral processing operations is described in "The Development of a Color Sensor System to Measure Mineral Compositions" by J.M. Oestreich et al., Minerals Engineering, Vol. 8, Nos. 1-2, pp. 31-39, 1995, herein incorporated by reference. The color sensor system described therein comprises a color video camera, a light source, a video-capture board, a computer, and a computer program that compares measured color vector angles to a previously stored calibration curve. Several cameras may be connected to a single color sensor computer or a single camera may simultaneously observe several locations using a network of fiber-optic cables.

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This preferred embodiment of the present invention may further comprise an advanced control system employing both pattern analysis by neural networks, as well as statistics and color vector analysis. For example, gray level dependence matrix methods are used to extract statistical features from digitized images of froths. These statistical features constitute a compact set of the essential data contained in the original image, which can then be related to the metallurgical parameters of the flotation process by means of neural nets. Either supervised neural nets, such as learning vector quantization systems, unsupervised nets, such as self-organized mappings, or a self-organizing neural net which can map high-dimensional input vectors to lower-dimensional maps in a topological order-preserving manner are used. Topological maps have the advantage that they can be used to track the performance of flotation processes on a continuous basis, as opposed to the discrete classification by other classification paradigms. For example, the thickener process could be monitored by means of a characteristic profile on a two-dimensional feature map, which would enable the early detection of deviation from optimal conditions by intelligent automation systems through comparison of the actual profile of the system with an ideal or optimal profile.

In addition to color, both viscosity and mobility of the bed slurry may be recorded and analyzed by visual means. Thus, in a further embodiment of this invention, a series of modules may be used to monitor different features with a high degree of accuracy. Thus, a machine vision system based on the interpretation of visual features of bed slurry structure has a modular structure, in which one module will distinguish between the bed levels based on differences in morphology, a next module will base the distinction on slurry mobility, another will extract chromatic information, another average particle size, and so on.

Referring now to FIGURE 3, a preferred embodiment of the present invention is shown wherein the intelligent control system includes one or more non-intrusive sensors for determining bed profile and other parameters. In FIGURE 3, a thickener is shown at 80. Thickener 80 includes a feed input 82 and a flocculant input 84. A rake is shown at 86 associated with a rake driving system 88. Feed is pumped from a feed

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source by feed pump 90 through feed control valve 92 and then into feed input 82. Similarly, flocculant is pumped from flocculant tank 94 via flocculant pump 96 and into flocculant inlet 84. As is well known, underflow is emitted from the bottom of tank 80 using an underflow pump 98 through an underflow control valve 100.

5 In accordance with an important feature of this preferred embodiment, a nearly non-intrusive sensor 102 is associated with thickener 80. As mentioned, by nearly non-intrusive, is meant that this sensor is not required to be lowered into the bed (as many conventional prior art probes) nor is the sensor required to be positioned onto struts or other structure within the tank. Instead, the sensor may be mounted above or
10 just beneath the liquid surface in a manner which does not impede the movement of rake 86 or the settling of materials within the bed. In the embodiment shown in FIGURE 3, the non-intrusive sensor 102 is positioned on walkway 104. Preferably, sensor 102 will obtain a bed profile over the entire bed (or at least that portion of the bed which is of interest), both horizontally and vertically. In order to obtain such a
15 complete profile, the sensor 102 is preferably mounted in a manner such that it may oscillate, describing an arcwise motion or move linearly along a radius of the tank. Also, a plurality of sensors 102 may be mounted in strategic positions along the bed so as to obtain the desired partial or complete bed profile. For example, with respect to thickeners, one area of particular interest is around the central feed well 108, where the
20 buildup of solids occurs. In order to monitor this build up of solids, a first sensor is positioned above the area adjacent to the feed well, and a second sensor is positioned midway to the periphery. Alternatively, a single sensor may be mounted on a carriage that moves it to the area of interest. In any case, sensor(s) 102 is mounted such that it is able to provide information for at least a plane of investigation through a sludge bed
25 or other area of interest. Prior interface analyzer sensors, for example, have been restricted to analysis along a single line of investigation. At most, such sensors can only provide information regarding different density or other measurements along that one line. Even where a computer program is provided that allows monitoring of profiles from multiple sensors, such a readout from multiple sensors could still not

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present a full two-dimensional depiction of the relevant plane of investigation. Instead, only multiple discrete lines of investigation are provided.

As shown by the dashed lines in FIGURE 3, sensor 102 communicates with control system 106 which consists of a suitable computer or microprocessor control device. In turn, control system 106 has the ability to communicate or control rake 86, feed pump 90, feed control valve 92, flocculant pump 96, underflow pump 98, and underflow control valve 100.

Non-intrusive sensor 102 preferably comprises an acoustic (ultrasonic or sonar) sensor or a millimeter wave radar sensor. An example of a suitable ultrasonic sensor is disclosed in U.S. Patent 5,148,700 (all of the contents of which are incorporated herein by reference). A suitable commercially available acoustic sensor is sold by Entech Design, Inc. of Denton, Texas under the trademark MAPS®. Preferably, the sensor is operated at a multiplicity of frequencies and signal strengths. Ordinarily, sensors operate to "see" the line of predetermined density in the plane of investigation. In other words, the ultrasonic signal is not returned by densities lighter than the predetermined density that lie above that line, and the signals do not penetrate to the greater densities that lie below the predetermined sludge density. However, by changing the frequency and strength of the signal, the predetermined density to be investigated is also changed.

Suitable millimeter wave radar techniques used in conjunction with the present invention are described in chapter 15 of Principles and Applications of Millimeter Wave Radar, edited by N.C. Currie and C.E. Brown, Artech House, Norwood, MA 1987. The ultrasonic technology referenced above can be logically extended to millimeter wave devices. It will be noted that while the ultrasonic and millimeter wave radar sensors are characterized as being "non-intrusive", the ultrasonic and sonar sensor does enter, to a limited extent, the top of the liquid above the bed, since contact is needed between the bed and the sensor in order for such sensors to properly function. The millimeter wave sensor will operate in a true, non-intrusive manner, being mounted above the liquid surface. Such limited penetration of the bed is shown schematically in FIGURE 3 by sensor 102.

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The output of sensor 102 provides information regarding the concentration of solid particles in the thickener bath, as a function of distance from the sensor head at a given time. This information is used to calculate a profile of the thickener, providing a digital picture of the solids concentration from top to bottom. The calculated profile
5 also indicates the relative height of the sludge bed (the settled solids on the bottom of the thickener). This profile may be numerically integrated to provide an accurate estimate of solids holdup in the thickener.

Sensors 102 may be configured to measure Doppler shift from the particles sensed in the settling zone, thus allowing the calculation of settling velocity. In
10 addition, the sensor 102 may be configured to measure the spectral reflectance from the surface of the sludge bed, allowing a calculation of solids concentration in the sludge bed. Other calculations may be made from the raw sensor data.

The preferred control system shown in FIGURE 3 utilizes a single sensor to determine one or more of the following: solids settling velocity, solids settling profile,
15 sludge bed level, solids holdup, and sludge bed solids content. These measurements, along with other measurements which may be made as needed can be used to control one or more of the following: feed rate, flocculant addition rate, and underflow rate. Control of feed and underflow rates may be made by changing pump speed, control valve opening, or both. Other control variables include, but are not limited to, volume
20 and mass flow rates of feed, overflow, and underflow; clarity or turbidity of feed, overflow and underflow; rake torque, and rake lift height.

Thus, while sensor 102, by itself, may be used to provide accurate measurements of sludge (or other material inventory), and control over the inventory by adjustment of feed and sludge withdrawal rates, preferably, sensor 102 is used in
25 combination with a feed mass meter 110 to effect further control of inventory and flocculant addition. Other parameters of particular interest in combination with sensor 102 is measurement and control of rake speed, rake lift, and rake torque.

Control decisions will be made by the "intelligent" control system (described above) to optimize the performance of the thickener as desired.

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Still other examples of suitable non-invasive sensors for use in the present invention are those known laser based sensors which detect and monitor the interfaces between, for example, liquid and solids or liquids of varying density. Such known laser detection systems are used to penetrate a liquid (i.e., water) layer and detect interfaces with solids and other dense objects and layers. Examples of such laser systems are disclosed in U.S. Patents 4,862,267; 4,964,721; 4,967,270; 5,013,917; and 5,450,125; as well as in the following publications: "Laser Remote Sensing" by Raymond M. Measures, published by John Wiley & Sons, Inc. (1984); M.F. Penny, B. Billard, R. Abbott "LADS - The Australian Laser Airborne Depth Sounder," International Journal of Remote Sensing, (10) 1463 (1989); and J. Lillycrop, J. Banic, "Advancements in the U.S. Army Corps. of Engineers Hydrographic Survey Capabilities: The SHOALS System," Marine Geodesy (15) 177 (1989), all of the contents of the foregoing patents and publications being incorporated herein by reference.

In a preferred embodiment of the present invention incorporating a laser based system of the aforementioned type, a red laser beam is split. Half the beam is then frequency-doubled, becoming green. When the dual beam is directed at, for example, a thickener tank, the red beam reflects from the surface of the water, providing a reference point, while the green beam penetrates the water and reflects from the interface of the settled solids with the water. Thus, the level of the settled solids may be calculated, using an instrument that does not require contact with the water, that is, using a non-invasive sensor.

While non-invasive monitoring, diagnosing, operating and controlling of various parameters and processes of thickeners, clarifiers, and settling tanks is a preferred embodiment of the present invention, simple monitoring operations using ultrasonic and sonar sensors is also within the scope of the present invention. Such monitoring operations are not required to be coupled to any computerized control operations. Thus, as shown in FIGURE 3, an ultrasonic sensor 112 pivots about a single axis to give a single planar view of, for example, the sludge bed 130, and then projects this view throughout the thickener 120 to give a three-dimensional representation. Such projection of a three-dimensional representation from a two-

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dimensional view is possible where the feed mechanisms result in generally uniform distribution of the influent across the thickener, and the withdrawal mechanisms result in a generally uniform withdrawal from the sludge bed. The operation of a rake arm 86 would facilitate the uniform distribution of materials throughout the tank. Such monitoring should compensate for the movement of a rake arm or other equipment into the plane of investigation of the sensor. Monitoring of this type may be used alone, or in combination with the other sensors and intelligent computer control systems described above.

It will be appreciated by those skilled in the art that the use of a non-intrusive sensor for providing a bed profile for thickeners, clarifiers and settling tanks will also be extremely useful for monitoring or controlling other processing tanks such as reaction vessels, which hold multiphase materials having either single or multiple components. Examples of such other types of processing tanks wherein the preferred embodiment of this invention will be extremely useful include chemical reaction vessels such as those used in fermentation, spray dryers, flash crystallizers and other reactor vessels. Thus, it will be appreciated that this invention also includes the use of the non-intrusive sensors and associated control systems shown in FIGURE 3 for use with any other type of processing tank holding multiphase materials such as the aforementioned reactors and like vessels. The use of such non-invasive sensors and associated control systems for other types of processing tanks is shown schematically in FIGURE 4 with like elements bearing the same identifying numerals with the addition of a prime. Thus, in FIGURE 4, the processing tank for holding a multiphase material which may contain a single or multiple component is shown at 106 and is associated with the same non-intrusive sensor control system as that depicted in FIGURE 3 whereby bed profiles can be accurately determined and subsequent control of the processing tank can then be executed.

Referring now to FIGURES 5-8, a sedimentation process, in which solids are separated from liquids by settling, e.g., a thickener, may be controlled using the output of a sonar sensor 210. For sedimentation control, sonar sensor 210 is designed to operate in either stationary or scanning mode. Sensor 210 is mounted just below the

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surface of the liquid in the process vessel 80, to achieve adequate acoustic coupling. The sonar signal is directed into the process liquid. The return signals, or echoes, arising from reflections along the signal path are detected, with their signal strengths and transit times being recorded. Given the speed of sound in the process liquid, the transit time allows calculation of the distance traveled by a given return signal. The return signal strength is proportional to the solids concentration at the point from which the reflection occurred. Thus sonar sensor 210, with appropriately configured signal processing, can calculate the solids concentration profile along its signal path.

Sensor 210 can operate in scanning mode, in which its sensing head, or transducer, rotates about an axis allowing its path to scan along a radius of the process vessel, as shown in FIGURES 5- 6. In this mode, sensor 210 will provide information regarding the level of solids being held at the bottom of the vessel 80. By integrating the scanned solids level over the entire radius of the vessel 80, the total contained solids, or solids holdup, can be estimated at a given time. The scanned profile will also provide indication of certain common process irregularities, including the buildup of solids on or in front of the rake 86 of thickener 80 or a clarifier. These irregularities are commonly described as islands or doughnuts. A typical video display of the sonar sensor signal is shown in FIGURE 7. Such displays are typically color or otherwise coded such that the signal strength is displayed visually.

When detailed information regarding the sedimentation process is required sensor 210 may operate in a fixed or stationary mode, with its transducer directed along a single path. This path will normally be vertical, but may be otherwise. In the fixed position, a detailed profile of the return signal may be recorded and processed. In general, that profile will resemble the one shown in FIGURE 8. The profile in FIGURE 8 shows the change in return signal strength in response to four primary variables from which key process control parameters can be calculated. Peak 1 represents the sudden change in solids concentration at the beginning of the settling zone, where the solids begin to thicken. Peak 2 represents the sudden change in solids concentration at the beginning of the sludge bed, where the settled solids reside and are compacted before leaving the process vessel. Area 3 represents the gradual change in

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solids concentration between the beginning of the settling zone and the beginning of the sludge bed, this rate of change being indicative of the settling rate in the settling zone, and area 4 represents the change in solids concentration from the beginning to some distance within the sludge bed, indicating the degree of compaction taking place within the sludge bed. The peak labeled five is due to near field reflection.

The process parameters, as derived from the sonar signal, will allow control of parameters such as the rate of flocculant addition and of the rate at which the settled solids are removed from the tank.

This sensor 210, with its two operating modes, may be part of an expert or intelligent control system 106, in which the sensor's operation is controlled by a computer program, which program is designed to optimize the process, and to operate the sensor as required to control the process in an optimal manner. The operational mode of the sensor 210 (scanning or fixed) will be selected either manually, or automatically. For automatic mode selection, the sensor system will include a microprocessor or similar control device, so that the sensor can communicate with a process control computer or system through a standard communications interface. Thus the sensor system will be capable of responding to various commands from a process control computer or system, which commands will control its scanning action.

More than one sensor may be used on a given process vessel, depending on the vessel size and the speed and attenuation of the sonar signal within the process media. Multiple sensors may also be used to provide more detailed information about the process, for optimized control.

The sensor system may also be provided with multiple transducers, so that it can operate at varying sonar frequencies. The sonar frequency of the sensor (scanning or fixed) will be selected either manually or automatically. For automatic signal strength selection, the sensor system will include a microprocessor or similar control device 106, so that the sensor can communicate with a process control computer or system through a standard communications interface. Thus the sensor system will be capable of responding to various commands from a process control computer or system, which commands will control its sonar frequency.

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The sensor system may also be configured to operate at varying levels of sonar signal strength (amplitude). Again, the sonar signal strength of the sensor (scanning or fixed) will be selected either manually or automatically. For automatic signal strength selection, the sensor system will include a microprocessor or similar control device
5 106, so that the sensor can communicate with a process control computer or system through a standard communications interface. Thus the sensor system will be capable of responding to various commands from a process control computer or system, which commands will control its scanning action.

The ability to select sonar frequency and signal strength will make it possible to
10 optimize the sensor's operation as the process media change, allowing for the maximum signal penetration through the liquid phase and into the settled solids.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present
15 invention has been described by way of illustrations and not limitation.

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What is claimed is:

CLAIM 1. A processing tank for holding or processing a multiphase material comprising:

at least one non-invasive sensor for continual sensing in real time of least one parameter associated with the tank;

a control computer associated with the tank and communicating with said sensor; and

a control device for controlling said thickener, said control device communicating with said control computer, wherein said control computer actuates said control device in response to input from said sensor.

CLAIM 2. The processing tank of claim 1, wherein said sensor is selected from the group comprising sensors to sense solids settling velocity, solids concentration in bed, solids settling profile, sludge bed level and solids hold-up.

CLAIM 3. The processing tank of claim 1, wherein said sensor is selected from the group comprising ultrasonic sensors, sonar sensors, laser sensors and millimeter wave radar sensors.

CLAIM 4. The processing tank of claim 1, wherein said control computer includes a process model which is at least partially self-generated and continually updated and adapted.

CLAIM 5. The processing tank of claim 4, wherein said process model is updated using at least one of the advanced analysis techniques selected from the group consisting of neural networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal processing, pattern recognition, and categorical analysis.

CLAIM 6. The processing tank of claim 1 wherein:

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said control device controls at least one of flocculant addition, rake speed, rake power consumption, torque on rake, rake lift height, feed rate, chemical addition rate, underflow rate, underflow density, underflow rheology and rake configuration.

5 CLAIM 7. The processing tank of claim 1 wherein:

said tank comprises a thickener.

CLAIM 8. The processing tank of claim 1 wherein:

10 said sensor is initialized by sweeping at least one of a range of frequencies, signal strengths and threshold returns.

CLAIM 9 A method for controlling a processing tank for holding or processing a multiphase material, comprising:

15 continual sensing in real time of at least one parameter associated with the processing tank using at least one non-invasive sensor system;
controlling the processing tank based, at least in part, on information from said non-invasive sensor system.

20 CLAIM 10. The method of claim 9, wherein said sensor is selected from the group comprising sensors to sense solids settling velocity, solids concentration in bed, solids settling profile, sludge bed level and solids hold-up.

25 CLAIM 11. The method of claim 9, wherein said sensor is selected from the group comprising ultrasonic sensors, sonar sensors, laser sensors and millimeter wave radar sensors.

30 CLAIM 12. The method of claim 9 wherein the controlling step includes control of at least one of chemical addition, rake speed, rake power consumption, torque on rake, rake lift height, feed rate, chemical addition rate, underflow rate, underflow density, underflow rheology and rake configuration.

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CLAIM 13. An apparatus for controlling a thickener comprising:
a computerized control system which continually monitors parameters
associated with the thickener process and executes control instructions in response to
said monitored parameters based on an internal process model which is at least
5 partially self-generated and continually updated and adapted.

CLAIM 14. The apparatus of claim 13 wherein said process model is updated by
means of at least one analysis method selected from the group comprising neural
10 networks, genetic algorithms, fuzzy logic, expert systems, statistical analysis, signal
processing, pattern recognition, categorical analysis, or a combination thereof.

CLAIM 15. The apparatus of claim 14 wherein said process model is further
generated and updated by at least one of feed forward or feedback loops.

15 CLAIM 16. A monitoring system for a processing tank for holding or processing a
multiphase material, comprising:

a sensor which senses in two dimensions a planar view of said multiphase
material, said sensor projecting said sensed view into a three dimensional
representation of said multiphase material.

20 CLAIM 17. The monitoring system of claim 16, wherein said sensor is an ultrasound
or sonar sensor.

CLAIM 18. The monitoring system of claim 16, wherein the sensor pivots about an
25 axis in order to generate said planar view.

CLAIM 19. The monitoring system of claim 16, wherein said sensor senses a planar
view of a sludge bed, said sensor projecting said sensed view into a three dimensional
representation of said sludge bed.

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CLAIM 20. The monitoring system of claim 16, wherein said processing tank comprises a thickener.

CLAIM 21. The monitoring system of claim 16 wherein:

5 said sensor is operable in a movable scanning mode where said sensor is directed along a plurality of paths and said sensor is operable in a stationary mode where said sensor is directed along a single path.

CLAIM 22. The monitoring system of claim 21 wherein:

10 said sensor is rotatable about at least one axis to allow said sensor to scan along a radius of the tank when operating in said scanning mode.

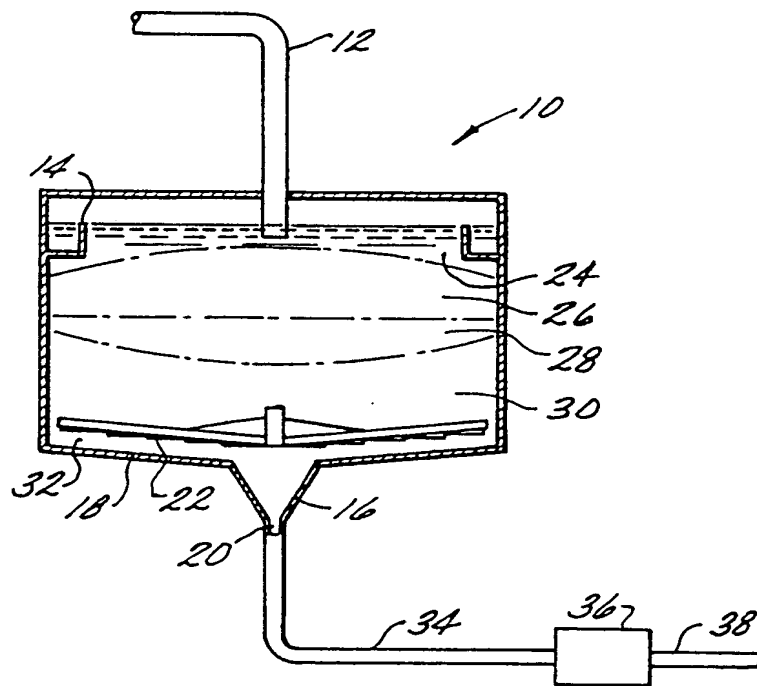
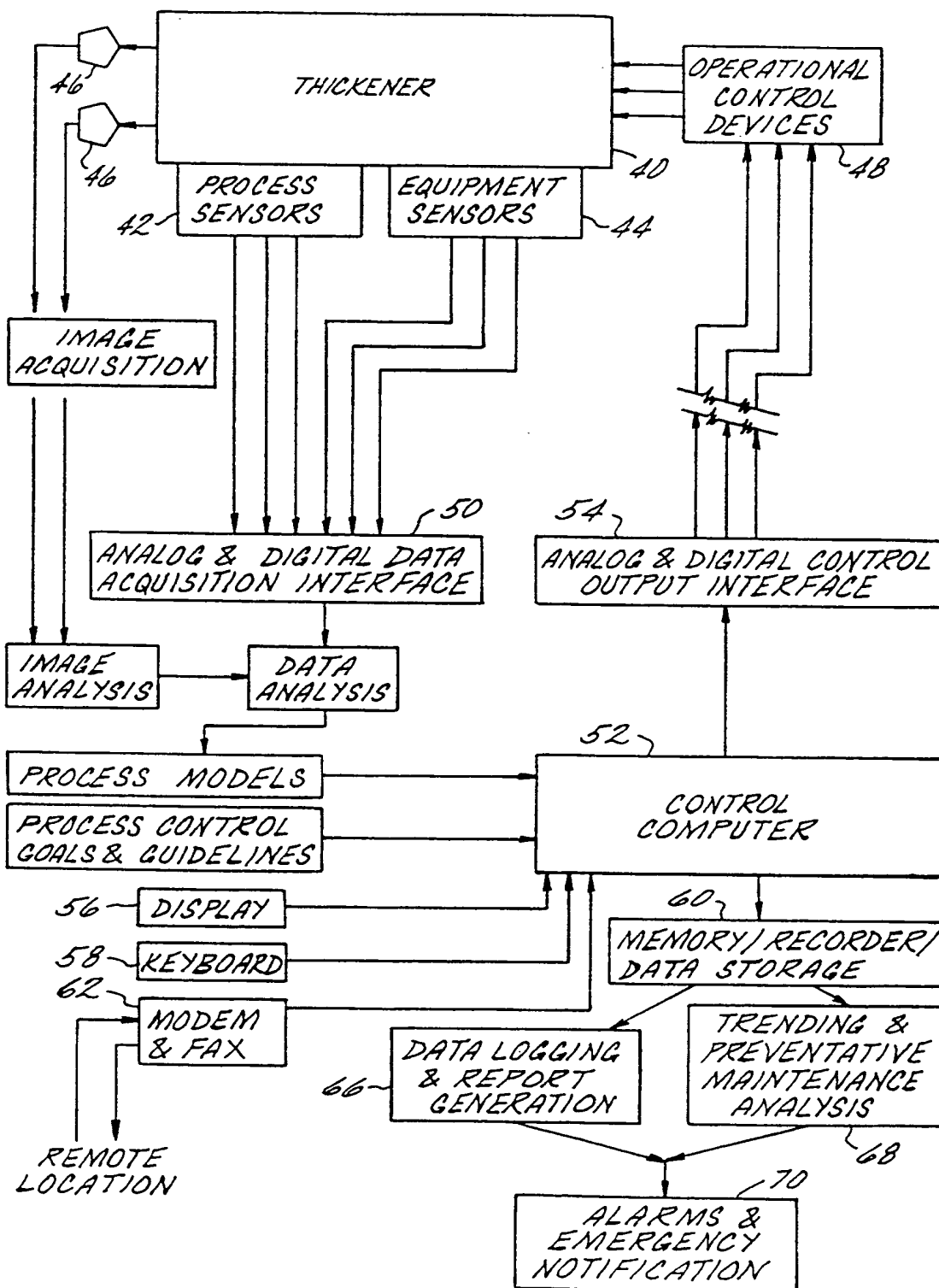


FIG. 1

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FIG. 2

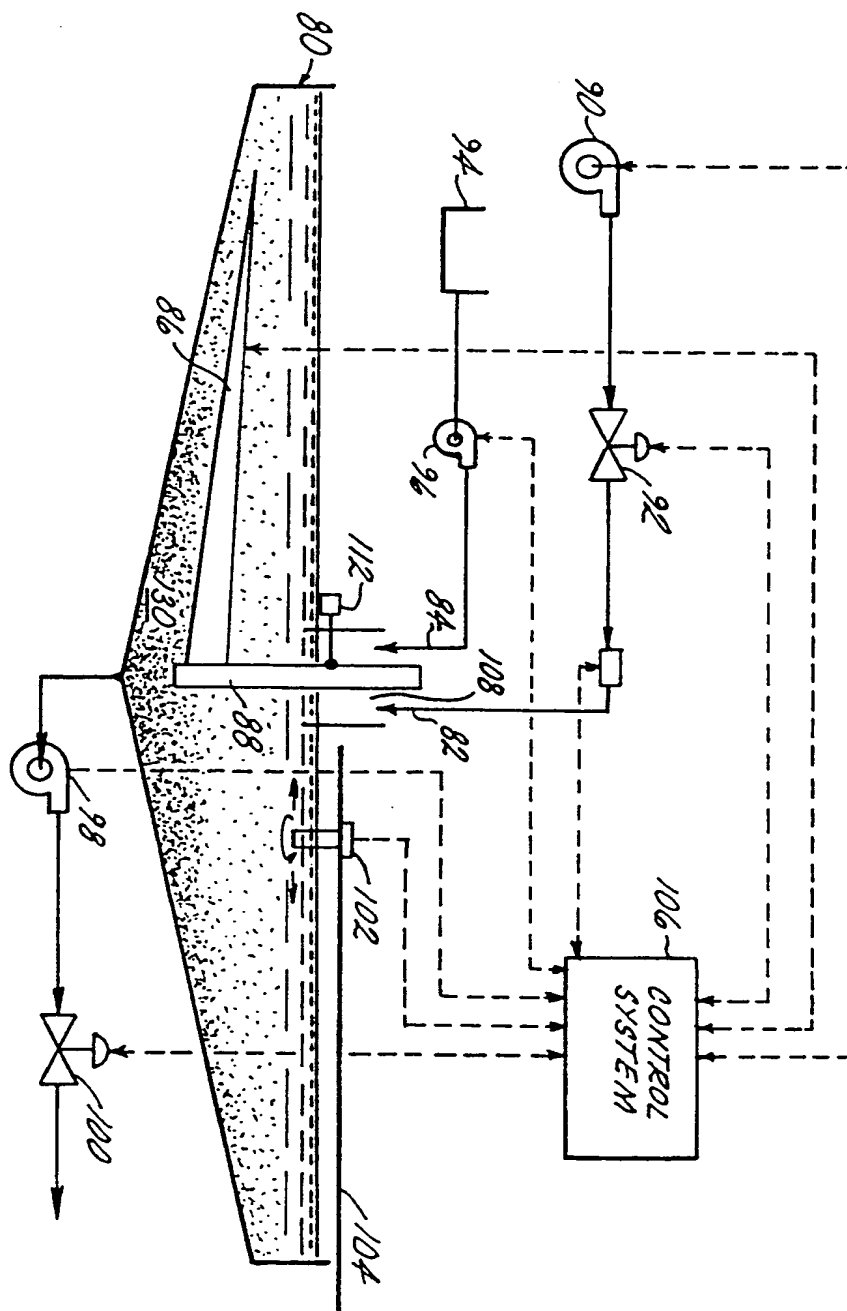


FIG. 3

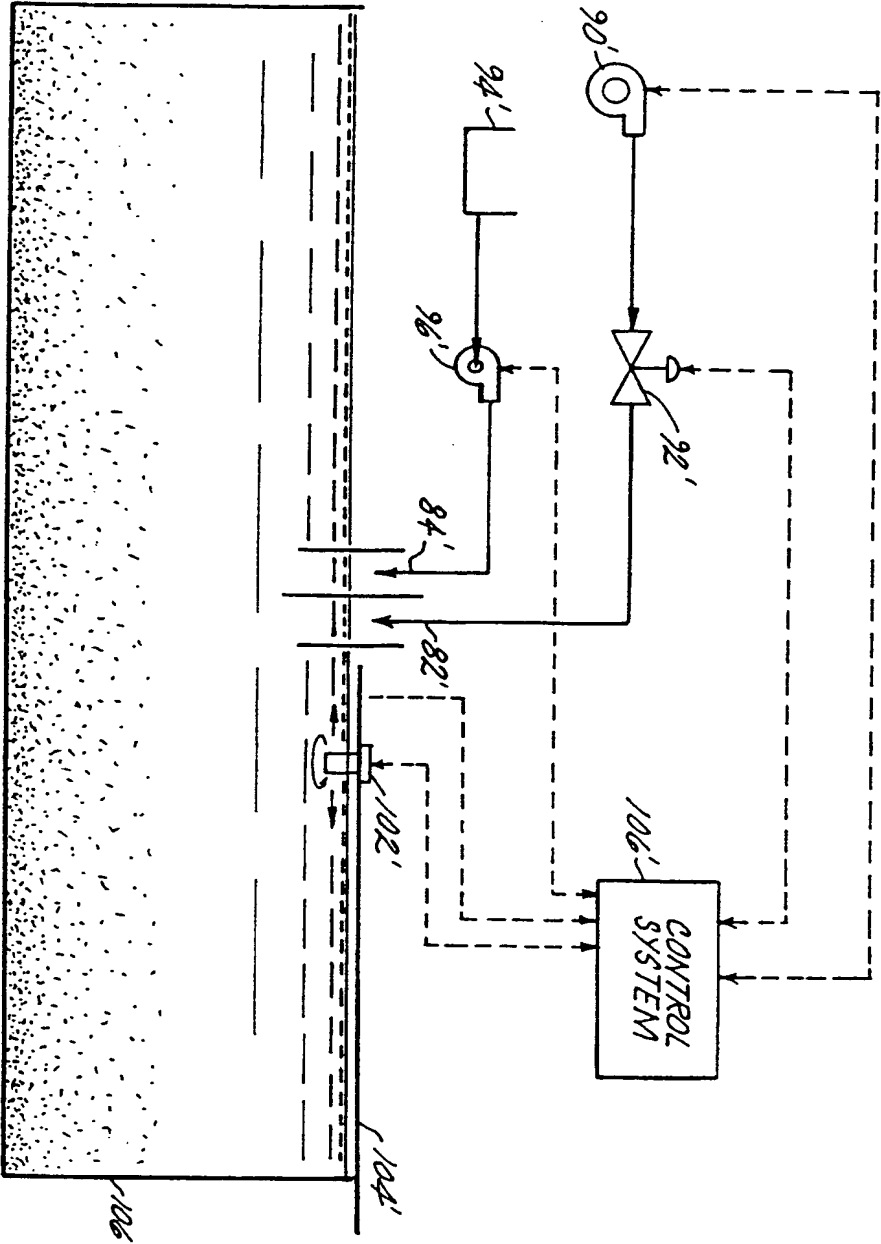


FIG. 4

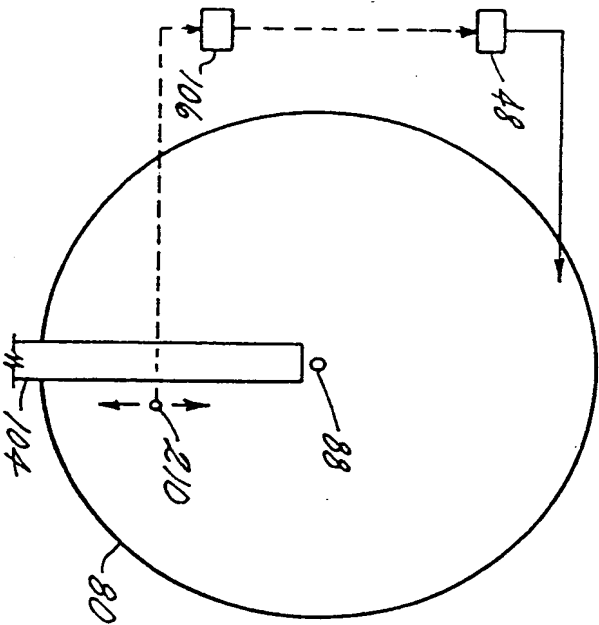


FIG. 5

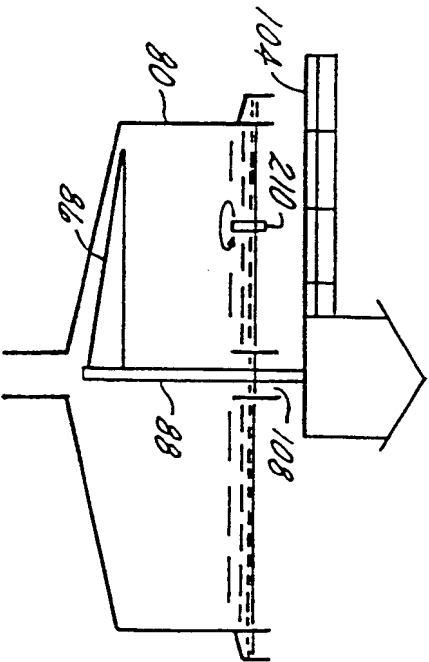


FIG. 6

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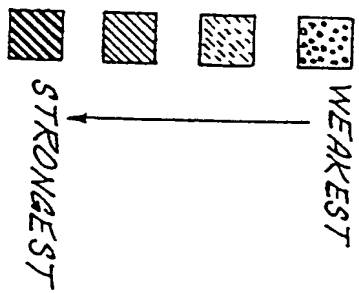
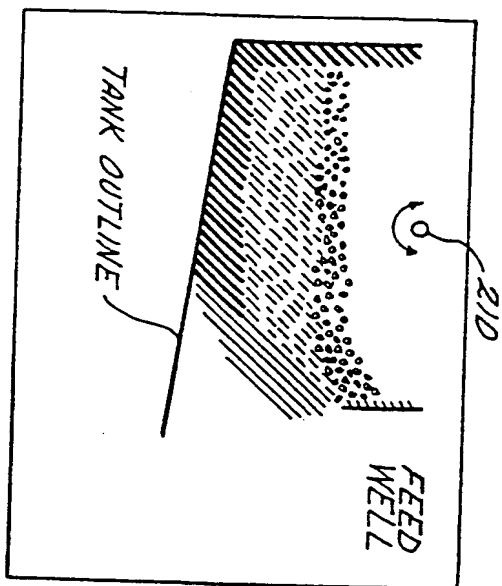


FIG. 7

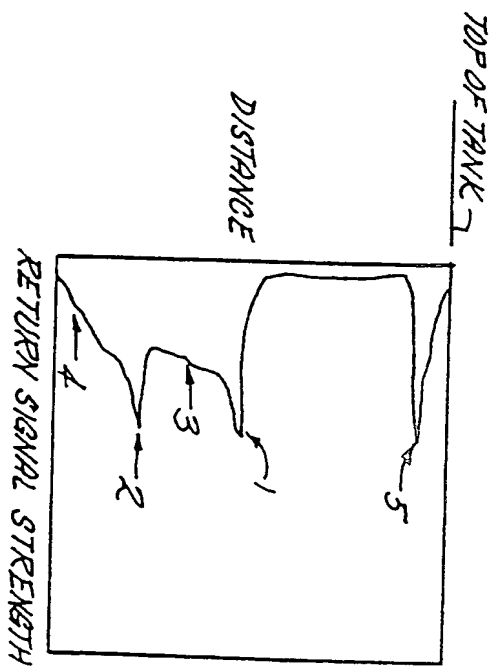


FIG. 8

100

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/08027

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 B01D21/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 677 315 A (GRAVER WATER COMPANY) 18 October 1995	1-3,6,7,9-12
Y	see column 2, line 32 - column 3, line 7	4,5,13,14
A		16,17,20
Y	--- PATENT ABSTRACTS OF JAPAN vol. 017, no. 321 (C-1072), 18 June 1993 & JP 05 031489 A (MEIDENSHA CORP), 9 February 1993, see abstract	4,5,13,14
A		
X	--- DE 43 36 459 A (BECKER THOMAS DIPL ING) 27 April 1995	1,2,6,9,10,12
A	see the whole document	4,5,13,14
	--- -/-	

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

12 August 1997

Date of mailing of the international search report

26.08.97

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (- 31-70) 340-2040, Tx. 31 651 epo nl,
Fax (- 31-70) 340-3016

Authorized officer

Marzenke, J

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/08027

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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